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2. Patent application number *(The Patent Office will fill in this part)* — **0003752.3**

3. Full name, address and postcode of the or of each applicant *(underline all surnames)*
   Patents ADP number *(if you know it)*

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   PO Box 53
   New Century Park
   Coventry
   CV3 1HJ
   751920001

   If the applicant is a corporate body, give the country/state of its incorporation — UNITED KINGDOM

4. Title of the invention — TRANSPONDER INTERFACE

5. Name of your agent *(if you have one)* — GILLIAN COCKAYNE

   "Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*

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Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*

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11. I/We request the grant of a patent on the basis of this application.

Signature

Date 18.2.2000

GILLIAN COCKAYNE

12. Name and daytime telephone number of person to contact in the United Kingdom

T Norris Tel. 01245 275133

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DUPLICATE

P62319U18; G11586

TRANSPONDER INTERFACE

The present invention is concerned with a transponder interface for an optical communication system. The present invention is also concerned with an optical communication system comprising a transponder interface.

Conventional optical communication systems comprise nodes interconnected by optical fibre waveguides. Communication traffic is communicated between the nodes by sending optical radiation through the waveguides, the radiation being modulated by the communication traffic. Each node is operable to convert modulated radiation received thereat into corresponding electrical signals. Moreover, each node is further operable to convert electrical signals thereat into corresponding modulated optical radiation and emit the radiation into waveguides connected thereto. Electrical signals can be input and output from the nodes if required, for example to provide signals to clients connected to the nodes and to receive signals from the clients for transmission within the systems.

In the aforementioned conventional systems, the optical radiation propagating therein typically has a wavelength in the order of 1550 nm. This wavelength corresponds to a radiation frequency of around 200 THz and theoretically offers a maximum communication bandwidth in the order of 100 THz taking into consideration the Nyquist criterion, namely that carrier radiation must have a carrier frequency at least twice that of the highest frequency of a signal modulated onto the carrier radiation to circumvent aliasing and information loss. It is conventional practice to partition radiation propagating in the conventional systems into wavebands, each waveband having associated therewith information-bearing radiation.

The inventors have appreciated that it is desirable in an optical communication system to be able to perform as much processing as possible within the optical domain to prevent the system having inherent bandwidth limitations associated with converting optical radiation to corresponding electrical signals. Moreover, the inventors have appreciated that it is also desirable to be able to redistribute communication traffic within the system between wavebands to ensure that the system is capable of providing its full communication bandwidth in operation when heavily loaded with communication traffic. Furthermore, the inventors have appreciate that it is highly desirable to be able to redistribute communication traffic within the system without having to

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convert information-bearing radiation into corresponding electrical signals which can represent a bandwidth limitation.

According to a first aspect of the present invention, there is provided a transponder interface for an optical communication system, the system comprising a plurality of optical paths for guiding information-bearing optical radiation, the radiation being partitioned into wavebands, characterised in that the interface is operable to isolate radiation of a first set of wavebands propagating along a first path of the paths and to translate information carried by the radiation of the first set of wavebands onto radiation of a second set of wavebands, and to selectively add the radiation of the second set of wavebands to the first path or to a second path of the paths.

The invention provides the advantage that the transponder interface is capable of waveband switching communication traffic conveyed through the system and redirecting waveband shifted communication traffic selectively between paths within the system.

In the interface, it is necessary to isolate radiation corresponding to wavebands which is to be shifted to other wavebands and then, if necessary, selectively redirected. Thus, conveniently, the first path comprises waveband selective diverting means for diverting radiation of at least the first set of wavebands to waveband translating means for translating information carried by the radiation of the first set of wavebands onto the radiation of the second set of wavebands for adding to the first or second path.

When outputting radiation of the second set of wavebands into the second path, it is important that the second path is not already carrying radiation corresponding to the second set of wavebands otherwise a conflict arises when radiation from the translating means is added to radiation already propagating in the second path. In order to ensure that there is no conflict, the interface preferably comprises in the second path waveband selective attenuating means for attenuating radiation of one or more wavebands propagating therethrough so that radiation of wavebands transmitted through the waveband attenuating means are non-coincident in wavelength with radiation present in the radiation output from the translating means for adding to radiation transmitted through the waveband attenuating means in the second path.

Likewise, when the radiation output from the translating means is output from the translating means and added to radiation propagating in the first path, it is important to ensure that no

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conflict occurs between co-incident wavebands. Thus, beneficially, the diverting means is operable to attenuate radiation of wavebands propagating therethrough so that radiation of wavebands transmitted through the diverting means are non-coincident with radiation of the second set wavebands output from the translating means and added to the radiation transmitted through the diverting means.

In practice, when constructing the interface, it is highly desirable to use proprietary optical components to save cost. One practical implementation of the interface is such that the translating means includes waveband selecting means for isolating radiation of a selected waveband diverted from the first path by the diverting means, detecting means for converting the isolated radiation into a corresponding electrical signal, and an optical radiation source modulatable by the signal and operable to generate radiation bearing the signal and at a waveband mutually different to the selected waveband, the generated radiation for selective output to the first or second path. Such an implementation of the translating means is feasible to construct using generally available components.

Alternatively, the translating means can be implemented such that radiation is transmitted solely in the optical domain without needing to be converted to corresponding electrical signals, thereby potentially providing enhanced interface bandwidth. Such an implementation is preferably such that the translating means includes waveband selecting means for isolating radiation of a selected waveband diverted from the first path by the diverting means, and an optical radiation source biased substantially at its lasing threshold, the source being operable to be stimulated by the isolated radiation such that stimulated radiation generated by the source is modulated by information carried by the isolated radiation, the stimulated radiation being at a waveband mutually different to the selected waveband, the stimulated radiation for selective output to the first or second path.

For satisfactory operation, it is desirable that the radiation source is maintained at its lasing threshold by a form of feedback. Thus, conveniently, the interface includes biasing means for monitoring the stimulated radiation from the source and determining thereby a bias current to apply to the source to ensure that it is operated substantially at its lasing threshold.

Preferably, the interface operates on information-bearing radiation in the optical domain without needing to convert the information into a corresponding electrical signal. Such operation

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circumvents bandwidth restrictions which arise when optical radiation is converted to corresponding electrical signals.

It is desirable that for radiation magnitude to be maintained at an adequate level within the system. Thus, beneficially, the interface comprises amplifying means for amplifying radiation received at the interface and radiation output from the interface.

The diverting means performs an important function within the interface and needs to be reconfigurable in practice to select different sets of wavebands. Such reconfigurability is achievable using commercially available proprietary optical components. Thus, conveniently, the diverting means includes:

(a) waveband selective filtering means for separating radiation of at least the first set of wavebands into spatially separated rays, each ray corresponding to radiation of an associated waveband; and

(b) liquid crystal attenuating means associated with each ray for selectively directing radiation corresponding to the waveband of the ray, the directed radiation being output to the translating means for use in generating the radiation of the second set of wavebands for selective output to the first or second path.

In a similar manner, it is also desirable that the waveband attenuating means should also be constructable using commercially available proprietary parts. Thus, beneficially, the waveband attenuating means includes:

(a) waveband selective filtering means for separating radiation of the one or more wavebands into spatially separated rays, each ray corresponding to radiation of an associated waveband; and

(b) liquid crystal attenuating means associated with each ray for selectively attenuating radiation corresponding to the waveband of the ray ,

such that radiation of wavebands transmitted through the waveband attenuating means are non-coincident in wavelength with radiation present in the radiation output from the translating means for adding to radiation transmitted through the waveband attenuating means in the second path.

According to a second aspect of the present invention, there is provided an optical communication system including a transponder interface according to the first aspect of the invention.

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Embodiments of the invention will now be described, by way of example only, with reference to the following diagrams in which:

Figure 1 is a schematic illustration of an optical communication system according to the invention comprising a plurality of mutually coupled bi-directional communication rings;

Figure 2 is an illustration of a first type of optical interface of the system shown in Figure 1, the interface connecting between two bi-directional communication rings and providing E-W direction connections from one ring to another;

Figure 3 is a schematic diagram of a channel control unit included within the optical interface illustrated in Figure 2;

Figure 4 is an illustration of a second type of optical interface of the system shown in Figure 1, the connection providing connection between oppositely directed fibre loops of a bi-directional ring;

Figure 5 is an illustration of a first embodiment of the invention, namely a transponder interface connecting two communication rings of the system shown in Figure 1;

Figure 6 is an illustration of a second embodiment of the invention, namely a transponder interface connecting two communication rings of the system shown in Figure 1; and

Figure 7 is an illustration of wavelength switching performed around channel control units of an interface of the system shown in Figure 1.

Referring now to Figure 1, an optical communication system according to the invention is indicated generally by 10. The system 10 comprises five interlinked bi-directional optical communication rings 20, 30, 40, 50, 60. The rings 20, 30, 40, 50, 60 are of diameters in a range of 10 km to 100 km and are operable to provide communication links at national and regional level. The rings 20, 30 include repeater nodes, for example a repeater node 65, represented by crosses around the rings 20, 30. Moreover, the ring 20 is connected through an interface 70 to the ring 30. Likewise, the ring 30 is connected through an interface 80 to the ring 40. The ring 40 is connected at first and second positions thereon through interfaces 90, 100 respectively to the ring 50. Likewise, the ring 50 is connected at third and fourth positions thereon through interfaces

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110, 120 respectively to the ring 60. The interfaces 70 to 120 are similar and will be described in more detail later.

Each of the rings 20 to 60 comprises two parallel optical fibre waveguide loops, a first of which conveys optical radiation in a clockwise direction around the ring and a second of which conveys optical radiation therethrough in an anticlockwise direction around the ring. Two loops are included within each ring for ensuring that the ring can continue to function in an event of one of the loops becoming defective, for example suffering a fibre break. Moreover, the two loops enable traffic to be allocated between the loops to ensure that the system 10 is optimally loaded with communication traffic.

Communication traffic is modulated onto optical radiation which propagates through the system 10. Each fibre loop of the rings 20 to 60 is operable to carry modulated optical radiation, the radiation comprising 32 distinct modulated radiation components corresponding to respective 32 communication channels. Each channel is separated from its neighbouring channels by a wavelength difference of 0.8 nm; such a wavelength difference is equivalent to a channel frequency spacing of 100 GHz. Thus, each fibre conveys optical radiation nominally of 1550 nm wavelength comprising 32 channels spread over a wavelength range of substantially 25 nm.

Operation of the system 10 will now be described communicating communication traffic from a node A on the ring 20 to a node B on the ring 60; the system 10 is capable of communicating between other nodes therein, however nodes A, B are used here as an example. An electrical signal is received at the node A which converts it to corresponding optical radiation associated with one of the 32 channels. The radiation propagates from the node A through the repeater node 65 to the interface 70 and therefrom through the repeater nodes of the ring 30 to the interface 80. The radiation propagates from the interface 80 anticlockwise around the ring 40 to the interface 100. Next, the radiation propagates from the interface 100 around part of the ring 50 to the interface 120 through which it passes to the ring 60 and therearound to the node B. The node B receives the radiation and converts it into a corresponding electrical signal. Propagation of the radiation through the system 10 from node A to node B is performed purely optically.

In the process of propagating from the node A to the node B, the radiation passes through a number of repeaters and interfaces which, although providing optical amplification, result in the radiation becoming degraded by attenuation and dispersion. Where possible, the system 10

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includes regenerators and also phase dispersion and equalisation correction units at its nodes. Such regeneration is preferable performed purely optically because conversion of the radiation to corresponding electrical signals for performing regeneration and then reconversion back to corresponding optical radiation is potentially a bandwidth limiting constraint on the system 10. Likewise, the phase dispersion and equalisation corrections are also preferably performed purely optically. Where it is not possible to perform such regeneration and dispersion correction purely optically in the system 10. conversion to electrical signals and regeneration and dispersion correction in the electrical domain is performed.

Referring now to Figure 2, there is shown a first type of optical interface included within the system 10, namely the interface 70 shown included within a dotted line 180. The ring 20 comprises a first clockwise fibre loop 210 through which radiation propagates in a direction from east (E) to west (W) through the interface 70. Moreover, the ring 20 comprises a second anti-clockwise fibre loop 200 through which radiation propagates in a direction from west (W) to east (E) through the interface 70. East (E) and west (W) directions here are used to indicate propagation direction in the diagrams and are unrelated to actual East-West geographical directions.

Likewise, the ring 30 comprises a first clockwise fibre loop 220 through which radiation propagates in a direction west (W) to east (E) through the interface 70. Moreover, the ring further includes a second fibre loop 230 through which radiation propagates in a direction from east (E) to west (W) through the interface 70.

The interface 70 includes twelve channel control units (CCU) 250 to 360 and associated optical amplifiers 400 to 550 interconnected as shown in Figure 2. The interface 70 further comprises fibre couplers 600 to 680 for coupling radiation from one fibre to another; the couplers are fabricated using optical fibre fusion splicing techniques although alternative types of couplers are useable in substitution. On account of its complexity, the interface 70 is a relatively expensive item but provides great flexibility when selectively coupling optical radiation between the rings 20, 30. Where such flexibility is not required, the interface 70 can be simplified to reduce cost; such simplification will be described later.

Detailed interconnection of the couplers 600 to 680, the CCUs 250 to 360 and the optical amplifiers 400 to 550 will now be described with reference to Figure 2. The couplers 600 to 680

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are mutually similar. Moreover, the amplifiers 400 to 550 are also mutually similar. Furthermore, the CCUs 250 to 360 are mutually similar.

The fibre 200 of the ring 20 from the westerly (W) direction is connected to an input port of the amplifier 400. The amplifier 400 includes an output port which is connected through an optical fibre to the coupler 600 and therethrough to an input port A of the CCU 250. The CCU 250 comprises an output port B which is connected through an optical fibre to the coupler 610 and therethrough to an input port of the amplifier 410. The fibre 200 in an easterly (E) direction is connected to an output port of the amplifier 410.

Likewise, the fibre 210 of the ring 20 from the easterly (E) direction is connected to an input port of the amplifier 430. The amplifier 430 includes an output port which is connected through an optical fibre to the coupler 640 and therethrough to an input port A of the CCU 260. The CCU 260 comprises an output port B which is connected through an optical fibre to the coupler 630 and therethrough to an input port of the amplifier 420. The fibre 210 in a westerly (W) direction is connected to an output port of the amplifier 420.

Similarly, the fibre 220 of the ring 30 from the westerly (W) direction is connected to an input port of the amplifier 520. The amplifier 520 includes an output port which is connected through an optical fibre to the coupler 650 and therethrough to an input port A of the CCU 350. The CCU 350 comprises an output port B which is connected through an optical fibre to the coupler 660 and therethrough to an input port of the amplifier 530. The fibre 220 in an easterly (E) direction is connected to an output port of the amplifier 530.

Likewise, the fibre 230 of the ring 30 from the easterly (E) direction is connected to an input port of the amplifier 550. The amplifier 550 includes an output port which is connected through an optical fibre to the coupler 680 and therethrough to an input port A of the CCU 360. The CCU 360 comprises an output port B which is connected through an optical fibre to the coupler 670 and therethrough to an input port of the amplifier 540. The fibre 230 in a westerly (W) direction is connected to an output port of the amplifier 540.

The couplers 600 to 640 are connected to the couplers 650 to 680 through a series of connection chains, each chain comprising an optical amplifier and an associated CCU connected in series.

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Connections from the ring 20 to the ring 30 will now be described. The coupler 600 includes first and second output ports. The first port of the coupler 600 is connected via an optical fibre through the amplifier 450 and then through the CCU 280 to a first input port of the coupler 660. Additionally, the second port of the coupler 600 is connected via an optical fibre through the amplifier 470 and through the CCU 300 to a first input port of the coupler 670. Moreover, the coupler 640 includes first and second output ports. The first port of the coupler 640 is connected via an optical fibre through the amplifier 490 and through the CCU 320 to a second input port of the coupler 670. Furthermore, the second port of the coupler 640 is connected via an optical fibre through the amplifier 500 and through the CCU 330 to a second input port of the coupler 660.

Next, connections from the ring 30 to the ring 20 will be described. The coupler 650 includes first and second output ports. The first port of the coupler 650 is connected via an optical fibre through the amplifier 440 and through the CCU 270 to a first input port of the coupler 630. Likewise, the second port of the coupler 650 is connected via an optical fibre through the amplifier 460 and then through the CCU 290 to a first input port of the coupler 610. Moreover, the coupler 680 includes first and second output ports. The first port of the coupler 680 is connected via an optical fibre through the amplifier 480 and then through the CCU 310 to a second input port of the coupler 630. Furthermore, the second port of the coupler 680 is connected via an optical fibre through the amplifier 510 and then through the CCU 340 to a second input port of the coupler 610.

Each CCU is capable of selectively attenuating radiation propagating therethrough corresponding to one or more of the 32 channels. Moreover, applying selective attenuation at the CCUs 250, 260, 350, 360 has the effect of diverting optical radiation to the couplers 600, 640, 650, 680 respectively preceding the CCUs. Such diversion also enables radiation to be added for the diverted channels at the couplers 610, 630, 660, 670 following the CCUs 250, 260, 350, 360 respectively.

In operation, the interface 70 is capable of providing purely optical paths between the rings 20, 30, such paths not being limited in bandwidth compared to when optical to electrical to optical conversion is performed as in conventional optical communication systems. Moreover, the interface 70 is capable of coupling specific selected channels from the ring 20 and directing them in either direction around the ring 30. Furthermore, in a reciprocal manner, the interface 70 is

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capable of coupling specific selected channels from the ring 30 and directing them in either direction around the ring 20.

In the communication system 10, it is not always necessary that its nodes provide the full connection functionality of the interface 70. When such extensive functionality is not required, the interface 70 can be simplified to reduce its complexity and cost by omitting some of the chains.

In the interface 70, regeneration and equalisation functions can be included within the aforementioned chains. It is preferable that such functions are performed optically if possible.

Optical equalization can be achieved using polarization dependent beam splitters and switched optical delay lines in a manner as described in a US patent no. US 5 859 939 which is incorporated herein by reference.

If it is not convenient to implement optical regeneration within the chains, electrical regeneration and equlisation can alternatively be employed therein although such regeneration and equalisation potentially imposes a bandwidth limitation on the system 10 and prevents the benefits, for example, from soliton propagation within the system 10 from being realised. Optical or electrical regeneration can, if required, be implemented in the repeater nodes around the rings 20, 30 in addition to, or in substitution for, regeneration within the interface 70.

In practice, commercially available optical amplifiers. CCUs and optical couplers can be connected together to construct the interface 70. For example, the optical amplifiers 400 to 550 are preferably proprietary units which incorporate optically-pumped erbium-doped super-fluorescent optical fibres as active optical gain components. Likewise, the CCUs 250 to 360 are commercially available from vendors based in the United States of America, for example one of the vendors supplies CCUs in units, each unit comprising a pair of CCUs. Each incorporates optical gratings, a matrix of liquid crystal apertures functioning as variable optical attenuators and free-space optical paths to achieve a compact construction and a low minimum insertion loss in the order of 6 dB from the CCU optical input port to the CCU optical output port when its attenuators are set to provide nominally zero attenuation. It is beneficial to the performance of the interface 70 to use such commercially available CCUs exhibiting low insertion losses in view

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of the number of CCUs employed within the interface 70; such low insertion loss CCUs reduce amplification requirements thereby improving system 10 signal-to-noise performance.

In order to further elucidate operation of the interface 70, the CCUs 250 to 360 will be described in further detail with reference to Figure 3. In Figure 3, there is shown an schematic representation of the CCU 250; the other CCUs 260 to 360 are similar in construction and performance to the CCU 250.

The CCU 250 includes an optical input port A for receiving radiation, an optical output port B for outputting radiation, an auxiliary optical output C, an auxiliary optical input D, and an electrical input port E for receiving electrical control signals for controlling operation of the CCU 250; the port E is, for example, used for receiving electrical signals for controlling attenuation settings of the attenuators. The CCU 250 comprises within it a demultiplexer 800, a multiplexer 810 and a matrix 818 of 32 liquid crystal attenuators shown included within a dotted line 820; an attenuator 815 is an example of one attenuator within the matrix 818. The demultiplexer 800 includes 32 optical outputs which are directed to convey radiation to their corresponding liquid crystal attenuators in the matrix 818. Outputs from the attenuators are directed to optical inputs of the multiplexer 810 which recombines radiation transmitted through the attenuators to provide output radiation at the port B. When the attenuators are set to attenuate radiation incident thereupon, the radiation is diverted towards a multiplexer 830 which is operable to combine the diverted radiation and provide a corresponding radiation output at the port C. Likewise, the port D is connected to a demultiplexer 840 which is operable to guide radiation input at the port D to the attenuators for propagating onwards to the multiplexer 810 for subsequent output at the port B. In the interface 70, the ports C and D of the CCUs are not normally used although they can be employed in special circumstances, for example when performing a wavelength shift to switch traffic from one channel to another; such a shift will be described later.

The attenuators are electronically controllable to provide an attenuation through each attenuator in a range of 0.1 dB to 30 dB. The CCUs supplied by one vendor based in the USA and incorporated within the interface 70 use free-space optics to obtain a minimum insertion loss of 6 dB. If the CCU where not constructed using such free-space optics, for example using more conventional fusion-spliced fibre optics, optical losses through the demultiplexer 800 and the multiplexer 810 would be around 7.5 dB and 4.5 dB respectively resulting in a total minimum insertion loss of 12 dB. Moreover, CCUs supplied by the vendor for use in the interface 70

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would be considerably more expensive and bulky were they not to employ such a compact free-space optical architecture.

The demultiplexer 800 is operable to filter composite radiation input at the port A into separate radiation components corresponding to each of the aforementioned 32 channels at 0.8 nm wavelength channel spacing. Thus, each attenuator can attenuate the radiation component corresponding thereto, thereby enabling each channel represented in radiation intput to the demultiplexer 800 to be selectively attenuated and diverted to the port C. In the interface 70, attenuation of a radiation component corresponding to a particular channel in the CCU 250 results in its radiation being diverted through the coupler 600 to its associated first and second output ports. A similar characteristic pertains to the CCUs 260, 350, 360 connected in-line in the rings 20, 30.

The CCUs 250 to 360 are controlled by electrical instructions sent thereto from a management control unit (not shown) tasked with routing communication traffic within the system 10 in response to client demand. The interface 70 is therefore designed to be highly reconfigurable thereby enabling communication traffic of any channels propagating in one of the rings to be selectively coupled to another of the rings in potentially both ring directions, namely in both directions of radiation propagation within the rings.

Although the interface 70 is capable of providing interconnection between bi-directional rings, for example between the rings 20, 30, there often arises a requirement to switch a particular channel within a bi-directional ring from one direction to another, for example from a clockwise loop of the ring to an associated anti-clockwise loop thereof. In order to achieve such a selective switching function, a simplified version of the interface 70 can be included in the ring. Such a simplified version of the interface 70 is illustrated in Figure 4 and indicated generally by 900. The simplified interface 900 comprises four CCUs 910 to 940, six optical amplifiers 950 to 1000 and four fibre couplers 1010 to 1040. The CCUs 910 to 940 are each similar to the CCU 250.

Interconnection of the CCUs, amplifiers and fibre couplers of the simplified interface 900 will now be described. The amplifiers 950, 960, the CCU 910 and the couplers 1010, 1020 are connected inline in the second fibre loop of the ring 20. A fibre 200 of the second loop in a westerly (W) direction is connected to an optical input of the amplifier 950. An optical output of the amplifier 950 is connected through an optical fibre to the coupler 1010 and therethrough to

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an optical input port A of the CCU 910. An optical output port B of the CCU 910 is connected through an optical fibre to the coupler 1020 and therethrough to an optical input of the amplifier 960. An optical output of the amplifier 960 is connected to the fibre 200 directed in an easterly (E) direction.

In a similar manner, the amplifiers 990, 1000, the CCU 920 and the couplers 1030, 1040 are connected inline in the first fibre loop of the ring 20. A fibre 210 of the first loop in an easterly (E) direction is connected to an optical input of the amplifier 1000. An output of the amplifier 1000 is connected through an optical fibre to the coupler 1040 and therethrough to an optical input port A of the CCU 920. An optical output port B of the CCU 920 is connected through an optical fibre to the coupler 1030 and therethrough to an optical input of the amplifier 990. An optical output of the amplifier 990 is connected to the fibre 210 directed in a westerly (W) direction.

The amplifier 970 and its associated CCU 1030 are connected in series and are operable to provide a first chain selectively linking communication traffic from the second loop comprising the fibre 200 to the first loop comprising the fibre 210. Likewise, the amplifier 980 and its associated CCU 940 are operable to provide a second chain selectively linking communication traffic from the first loop to the second loop.

In operation, the simplified interface 900 can block, by virtue of the CCUs 910, 920, communication traffic associated with specific channels flowing within the loops and direct the traffic to a chain which can selectively transmit one or more of the channels depending upon instructions sent to the port E of its CCU. In general, the CCU 910 will be set to attenuate radiation of one or more channels which the CCU 930 is set to selectively transmit. Likewise, the CCU 920 will be set to attenuate radiation of one or more channels which the CCU 940 is set to selectively transmit. Thus, the interface 900 enables specific selected channels to be switched from propagating in one direction around the ring 20 to an opposite direction relative thereto. The interface enables the volume of communication traffic to be more equally distributed between the two loops of the ring 20, thereby enabling the system 10 to be more fully utilised. The interface 900 also provides optical amplification which assists to maintain optical radiation amplitude within the system 10.

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When coupling communication traffic between rings in the system 10, and also when switching direction of selected channels within one or more rings of the system 10, it is frequently convenient to shift communication traffic from one channel to another along a particular loop or ring; this is often referred to as wavelength shifting. Wavelength shifting enables the channels of the system 10 to be fully utilised to carry communication traffic thereby assisting to optimise the traffic throughput capacity of the system 10.

Such wavelength shifting is preferably performed purely in the optical domain to avoid imposing bandwidth restrictions on the system 10; optical wavelength shifting can be achieved using optical heterodyne techniques in non-linear optical components capable of performing optical mixing. Alternatively, wavelength shifting can also be achieved by using optical radiation at a first frequency to pump a laser biased near its lasing threshold and tuned to output optical radiation at a second frequency, thereby enabling communication traffic modulated onto the radiation of the first frequency to be modulated onto radiation output from the laser at the second frequency: if the radiation of the first frequency corresponds to one channel of the system 10 and radiation of the second frequency to another channel, switching of traffic from one channel to another can be achieved.

Wavelength switching can also be performed by converting modulated radiation at a first wavelength associated with a specific channel of the system 10 to a corresponding electrical signal and then using the electrical signal to amplitude modulate a laser to output radiation amplitude modulated by the electrical signal at a second wavelength associated with another specific channel of the system 10. Such wavelength switching is often found to be required when coupling communication traffic from one ring of the system 10 to another thereof.

Referring now to Figure 5, there is shown a first embodiment of a transponder interface of the invention connecting two communication rings of the system 10. The interface is indicated generally by 1200 and comprises two CCUs 1210, 1220, four optical amplifiers 1230 to 1260, four optical couplers 1270 to 1300, a tunable filter and detector 1310, and a modulated tunable laser source 1320. Each of the two CCUs 1210, 1220 are similar to the CU 250 described earlier. The amplifiers 1230, 1240, the CCU 1210 and the couplers 1270, 1280 are connected into the second loop of the ring 20, the loop including the fibre 200. Likewise, the amplifiers 1250, 1260, the CCU 1220 and the couplers 1290, 1300 are connected into the first loop of the ring 30, the loop including the fibre 210. The tunable filter and detector 1310 and the source 1320 constitute

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a waveband translator indicated by 1332 and shown included within a dotted line 1330. The translator 1332 is connected to the couplers and operable to wavelength shift a selected channel from one of the loops and output at another wavelength back onto the same loop or an alternative loop.

Interconnection within the interface 1200 will now be described. The fibre 210 of the first loop of the ring 20 from a westerly (W) direction is connected to an optical input of the amplifier 1230. An optical output from amplifier 1230 is connected to the coupler 1270 and therethrough to an optical input port A of the CCU 1210. An optical output port B of the CCU 1210 is connected via an optical fibre to the coupler 1280 and therethrough to an optical input of the amplifier 1240. The fibre 200 in an easterly (E) direction of the second loop is connected to an optical output of the amplifier 1240.

Likewise, the fibre 210 of the first loop of the ring 30 from an easterly (E) direction is connected to an optical input of the amplifier 1260. An optical output from amplifier 1260 is connected to the coupler 1300 and therethrough to an optical input port A of the CCU 1220. An optical output port B of the CCU 1220 is connected via an optical fibre to the coupler 1290 and therethrough to an optical input of the amplifier 1250. The fibre 210 in a westerly (W) direction of the first loop of the ring 30 is connected to an optical output of the amplifier 1250.

An optical output of the coupler 1270 is connected through an optical fibre to a first optical input of the tunable filter and detector 1310. Similarly, an optical port of the coupler 1300 is connected through an optical fibre to a second optical input of the filter and detector 1310.

An optical input of the coupler 1290 is connected through an optical fibre to a first optical output of the laser source 1320. Similarly, an optical input port of the coupler 1280 is connected through an optical fibre to a second optical output of the laser source 1320.

The tunable filter and detector 1310 includes a coupler to combine radiation received at its first and second ports, and also a tunable filter and a detector. It is operable to receive radiation, filter out radiation corresponding to a channel to be shifted and to detect the filtered radiation to generate a corresponding demodulated electrical signal which is provided to the output P1. The source includes a tunable laser for generating output radiation modulated by an electrical signal applied at the electrical input P2 of the source 1320. When the laser source 1320 is tuned to

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operate at a frequency which is mutually different from the filter frequency of the of the filter and detector 1310, frequency shifting of traffic between channels is achieved when the electrical signal output at P1 is injected at the input P2.

The CCU 1210 is operable to attenuate one or more selected channels included in radiation propagating around the second loop of the ring 20. Such attenuation diverts the attenuated radiation to the coupler 1270 and onwards to the first input of the filter and detector 1310. When the filter and detector 1310 is tuned to the wavelength of a channel attenuated at the CCU 1210, radiation propagates through to the detector and gives rise to an electrical signal at the output P1. The signal from the output P1 is directed to the input P2 and is operable to modulate radiation generated by the source 1320 which selectively outputs the modulated radiation at the first or second output depending upon instructions received from the management control unit (not shown). When the radiation is output at the second output of the laser source 1320, it propagates to the coupler 1280 and is coupled into the second loop to propagate further in an easterly (E) direction through the fibre 200 around the second loop of the ring 20. Conversely, when the radiation is output at the first output of the laser source 1320, it propagates to the coupler 1290 and passes therethrough to the amplifier 1250 and onwards in a westerly (W) direction along the fibre 210 of the first loop of the ring 30.

The CCU 1220 is also operable to selectively attenuate radiation corresponding to one or more selected channels propagating in the first loop of the ring 30 and direct the radiation through the coupler 1300 to the second input of the filter and detector 1310. The filter and detector 1310 are operable to isolate radiation components and detect them to generate a corresponding electrical signal at the output P1. The electrical signal, when directed to the source 1320, modulates the source 1320 to provide modulated radiation which is selectively directable to the ring 20 or to the ring 30.

The interface 1200 is thus capable of selectively shifting communication traffic from one channel to another. Moreover, it is further capable of receiving such traffic from either the ring 20 or the ring 30 and selectively outputting the traffic, when channel shifted, onto either the ring 20 or the ring 30. The interface is thus capable of performing flexible and reconfigurable frequency shifting and routing functions.

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Referring now to Figure 6, there is shown indicated generally by 1400 a second embodiment of a transponder interface according to the invention. The interface 1400 is similar in function to the 1200 and includes parts present in the interface 1200 except that the transponder 1332 in the interface 1200 is substituted by a transponder 1410 in the interface 1400.

The transponder 1410 is shown in Figure 6 included within a dotted line 1412. The transponder 1410 comprises a tunable filter 1420 including dual selectable input ports (E, W), a tunable laser source 1430, and a bias control unit 1440. An optical output port Q_1 of the filter 1420 is connected to an optical input Q_2 of the source 1430. Moreover, the source 1430 includes two optical output ports (E-W) and an optical monitoring port Q_3. The port Q_3 is connected to an input port of the bias control unit 1440. The unit 1440 also comprises an electric output S_1 is connected to an electrical input S_2 of the source 1430.

Operation of the transponder interface 1440 will now be described with reference to Figure 6. Information bearing radiation partitioned into 32 wavebands propagates along the fibre 200 from a westerly direction to the amplifier 1230 which amplifies the radiation to provide corresponding amplified radiation which further propagates from the amplifier 1230 through the coupler 1270 to the CCU 1220. The CCU 1220 receives routing instructions from the management control unit (not shown) to divert radiation of one or more selected wavebands back through to the coupler 1270 and therefrom to the transponder 1400, namely to the W input port of the tunable filter 1420. The filter 1420 receives the diverted radiation by selecting its W input port under instruction from the management control unit. The filter 1420 then filters out radiation associated with a specific waveband to be frequency shifted, and subsequently outputs the filtered radiation at its output port Q_1. The filtered radiation is then used in the source 1430 as stimulating radiation for a tunable laser incorporated therein. The laser is tuned to a different wavelength than that of the filtered radiation. The filtered radiation stimulates emission from the laser to provide corresponding stimulated radiation which is selectively output, depending upon instruction from the management control unit, to either the W or E port of the source 1430. When the W port is selected, the stimulated radiation is diverted to the coupler 1290 and continues by propagating in a westerly direction along the fibre 210. Conversely, when the E port is selected, the stimulated radiation is diverted to the coupler 1280 and continues by propagating in an easterly direction along the fibre 200.

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The bias control unit 1440 is operable to monitor the stimulated radiation from the laser. If the radiation is present but appears unmodulated, the unit 1440 interprets this as the laser being biased too strongly above its lasing threshold; the unit 1440 responds by reducing a laser bias current supplied at the S_1 output which, in turn, reduces current flowing through the laser. Conversely, if no radiation is present, the unit 1440 interprets this as the laser being biased too weakly below its lasing threshold; the unit 1440 responds by increasing the laser bias current supplied at the S_1 output which, in turn, increases current flowing through the laser.

The interface 1400 can also respond to information-bearing radiation propagating along the fibre 210 from an easterly direction where the radiation propagates to the amplifier 1260 which amplifies the radiation to provide corresponding amplified radiation. The amplified radiation propagates through the coupler 1300 to the CCU 1220. The CCU 1220 is instructed by the management control unit to divert radiation of one or more selected wavebands in the amplified radiation back to the coupler 1300 and therethrough to the E input port of the filter 1320. The filter 1420 is instructed by the management control unit to accept radiation at the E port. Processing of the selected wavebands of the radiation present at the E port occurs in the source 1430 as described above where corresponding shifted radiation can be output to either the fibre 200 in a easterly direction or to the fibre 210 in a westerly direction depending upon instructions sent from the management control unit.

Thus, in operation, the transponders 1200, 1400 not only provide wavelength switching but also channel communication traffic rerouting not only in east and west directions but also in north and south directions: the north and south directions referred to here, in a similar manner to the east and west directions, are not related to geographical directions but merely used to refer to direction of propagation in the diagrams.

In the interfaces 1200, 1440, a plurality of the transponders 1332, 1410 can be included in parallel so that radiation of more than one waveband can be simultaneously shifted to other wavebands. Such a modification requires that the couplers 1270, 1300 should have multiple optical outputs, each output connected to a corresponding transponder. Likewise, the couplers 1280, 1290 should also have multiple optical inputs, each input connected to a corresponding transponder.

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The transponder 1332 shown in Figure 5 included within the dotted line 1330, or alternatively the transponder 1410 shown in Figure 6 included within the dotted line 1412, can be included within the interface 70 illustrated in Figure 1 to provide a modified interface according to the invention indicated generally by 1500 in Figure 7. Such a modified interface 1500 not only provides a high degree of reconfigurable channel connection control but also enable communication traffic to be switched between channels to ensure that the system 10 is operating optimally to circumvent grossly unequal distribution of traffic between available channels.

Within the interface 1500, each transponder 1332, 1410 is connected with its filter inputs coupled to its associated CCU optical output port C, and its source outputs coupled to its associated CCU optical input port D. Although transponders 1332 are illustrated coupled to the CCUs 270, 330 only, more transponders can be incorporated into the interface 1500 if necessary such that up to all the CCUs 270 to 340 have associated transponders capable of performing wavelength shifting of communication traffic directed therethrough.

It will be appreciated that modifications can be made to the system 10, and to the interfaces 70, 900, 1200, 1400, 1500 without departing from the scope of the invention. For example, although the system 10 is illustrated with a sending node A and a receiving node B, the system 10 can have a large number of sending and receiving nodes distributed generally therearound. The system 10 can be modified to include a combination of ring and linear communication paths interlinked by interfaces of a type included amongst the interfaces 70, 900, 1200, 1400, 1500 at various locations. Moreover, the interfaces 70, 900, 1200, 1400, 1500 can be simplified or made more complex as described above to suit particular system reconfiguration requirements. For example, the system 10 can be modified to include 100 bi-directional rings, each ring comprising 10 interfaces similar to the interface 900, the rings interconnected together through interfaces similar to the interface 1200 or to the interface 1500.

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CLAIMS

1. A transponder interface for an optical communication system, the system comprising a plurality of optical paths for guiding information-bearing optical radiation, the radiation being partitioned into wavebands,

characterised in that the interface is operable to isolate radiation of a first set of wavebands propagating along a first path of the paths and to translate information carried by the radiation of the first set of wavebands onto radiation of a second set of wavebands, and to selectively add the radiation of the second set of wavebands to the first path or to a second path of the paths.

2. An interface according to Claim 1 comprising in the first path waveband selective diverting means for directing radiation of at least the first set of wavebands to waveband translating means for translating information carried by the radiation of the first set of wavebands onto the radiation of the second set of wavebands for adding to the first or second path.

3. An interface according to Claim 2 wherein the interface comprises in the second path waveband selective attenuating means for attenuating radiation of one or more wavebands propagating therethrough so that radiation of wavebands transmitted through the attenuating means are non-coincident in wavelength with radiation present in the radiation output from the translating means for adding to radiation transmitted through the waveband attenuating means in the second path.

4. An interface according to Claim 2 wherein the diverting means is operable to attenuate radiation of wavebands propagating therethrough so that radiation of wavebands transmitted through the diverting means are non-coincident with radiation of the second set of wavebands output from the translating means and added to the radiation transmitted through the diverting means.

5. An interface according to Claim 2, 3 or 4 wherein the translating means includes waveband selecting means for isolating radiation of a selected waveband diverted from the first path by the diverting means, detecting means for converting the isolated radiation into a corresponding electrical signal, and an optical radiation source modulatable by the signal and operable to

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generate radiation bearing the signal and at a waveband mutually different to the selected waveband, the generated radiation for selective output to the first or second path.

6. An interface according to Claim 2, 3 or 4 wherein the translating means includes waveband selecting means for isolating radiation of a selected waveband diverted from the first path by the diverting means, and an optical radiation source biased substantially at its lasing threshold, the source being operable to be stimulated by the isolated radiation such that stimulated radiation generated by the source is modulated by information carried by the isolated radiation, the stimulated radiation being at a waveband mutually different to the selected waveband, the stimulated radiation for selective output to the first or second path.

7. An interface according to Claim 6 including biasing means for monitoring the stimulated radiation from the source and determining thereby a bias current to apply to the source to ensure that it is operated substantially at its lasing threshold.

8. An interface according to Claim 1, 2, 3, 4, 6 or 7 wherein the interface operates on information-bearing radiation in the optical domain without needing to convert the information into a corresponding electrical signal and back again to corresponding optical radiation.

9. An interface according to any preceding claim comprising amplifying means for amplifying radiation received at the interface and radiation output from the interface.

10. An interface according to Claim 2 wherein the diverting means includes:

(a) waveband selective filtering means for separating radiation of at least the first set of wavebands into spatially separated rays, each ray corresponding to radiation of an associated waveband; and

(b) liquid crystal attenuating means associated with each ray for selectively directing radiation corresponding to the waveband of the ray, the directed radiation being output to the translating means for use in generating the radiation of the second set of wavebands for selective output to the first or second path.

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11. An interface according to Claim 3 wherein the waveband attenuating means includes:
(a) waveband selective filtering means for separating radiation of the one or more wavebands into spatially separated rays, each ray corresponding to radiation of an associated waveband; and
(b) liquid crystal attenuating means associated with each ray for selectively attenuating radiation corresponding to the waveband of the ray ,

such that radiation of wavebands transmitted through the waveband attenuating means are non-coincident in wavelength with radiation present in the radiation output from the translating means for adding to radiation transmitted through the waveband attenuating means in the second path.

12. An optical communication system including a transponder interface according to any preceding claim.

13. A transponder interface substantially as hereinbefore described with reference to one or more of Figures 1 to 7.

14. An optical communication system substantially as hereinbefore described with reference to one or more of Figures 1 to 7.

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ABSTRACT

The invention provides a transponder interface (1200, 1400, 1500) for an optical communication system (10) comprising a plurality of mutually interconnected bi-directional optical waveguide rings (20, 30, 40, 50, 60) in which radiation modulated with communication traffic propagates. The radiation is partitioned into 32 distinct wavebands. Interfaces (70, 80, 90, 100, 110, 120, 1200, 1400, 1500) are included in the system (10) where communication traffic propagating in the rings transfers from one ring to another. Each interface (70, 1400, 1500) is capable of providing an all-optical waveband reconfigurable communication link between the rings (20, 30, 40, 50, 60). At each interface (70, 1400, 1500), conversion of optical radiation to corresponding electrical signals is not required when transferring communication traffic from one ring to another and from waveband to another, thereby providing the system (10) with a potentially larger communication bandwidth compared to conventional optical communication systems.

Figure 1 should accompany the abstract.

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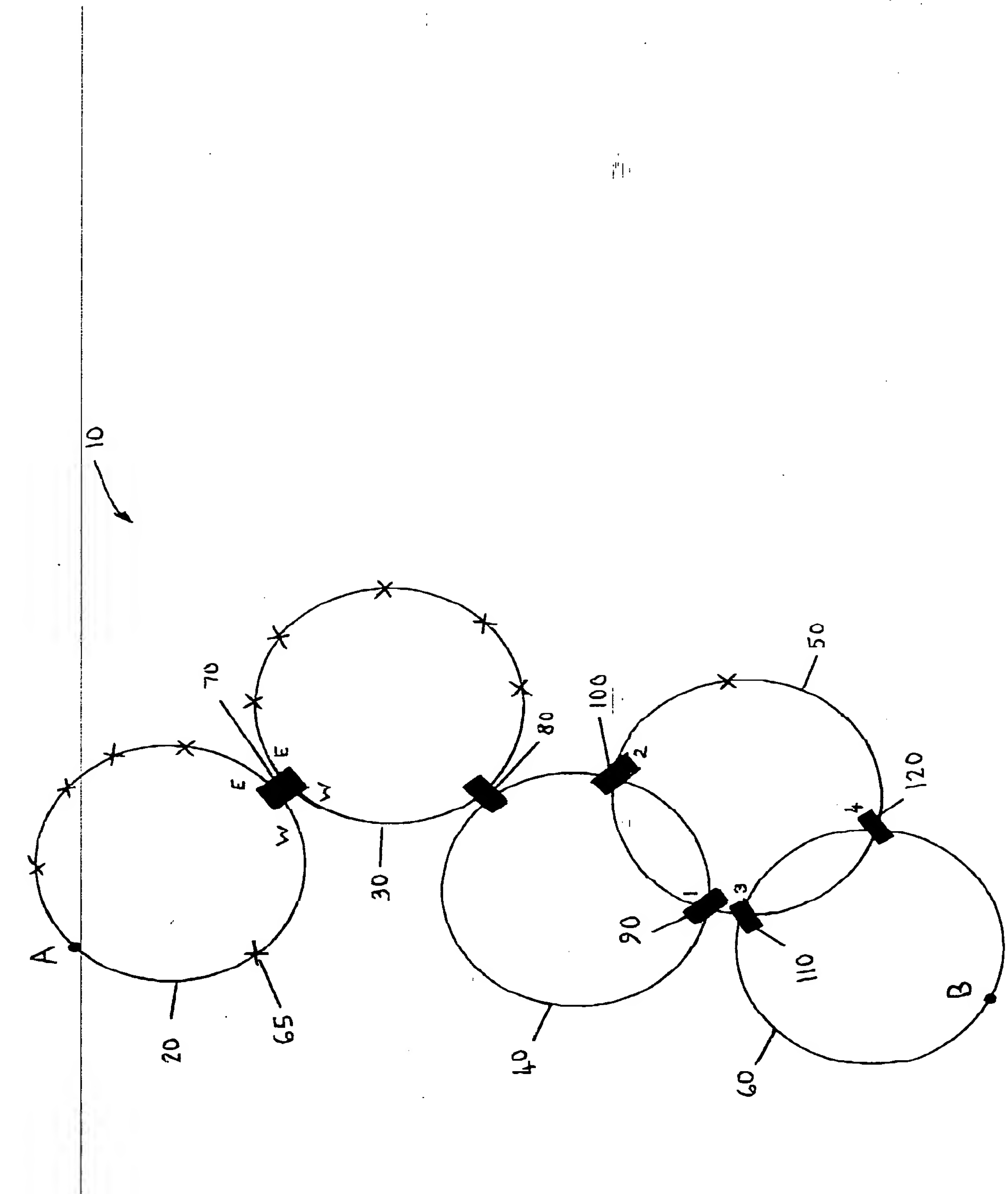

Fig. 1

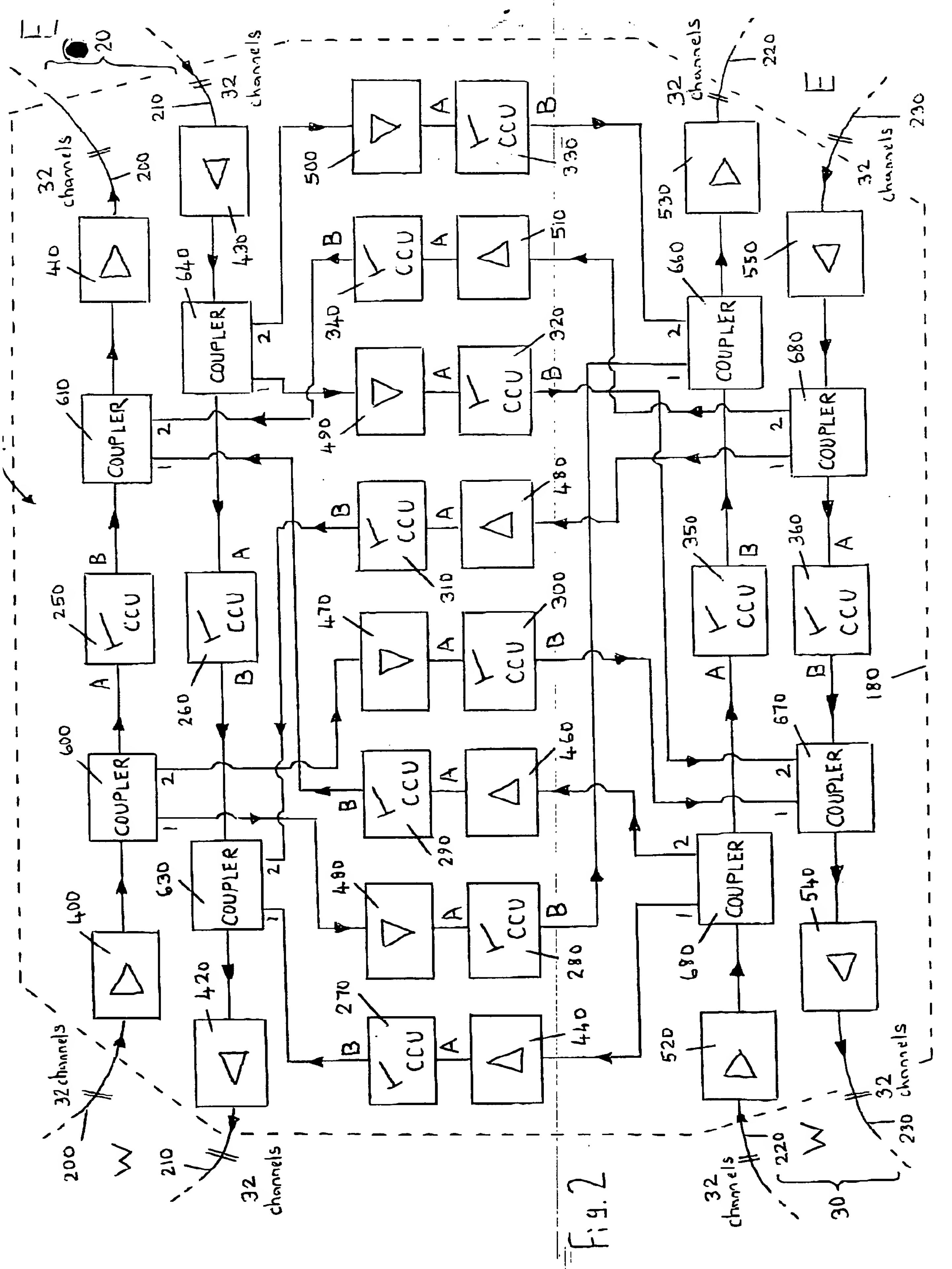

Fig. 2

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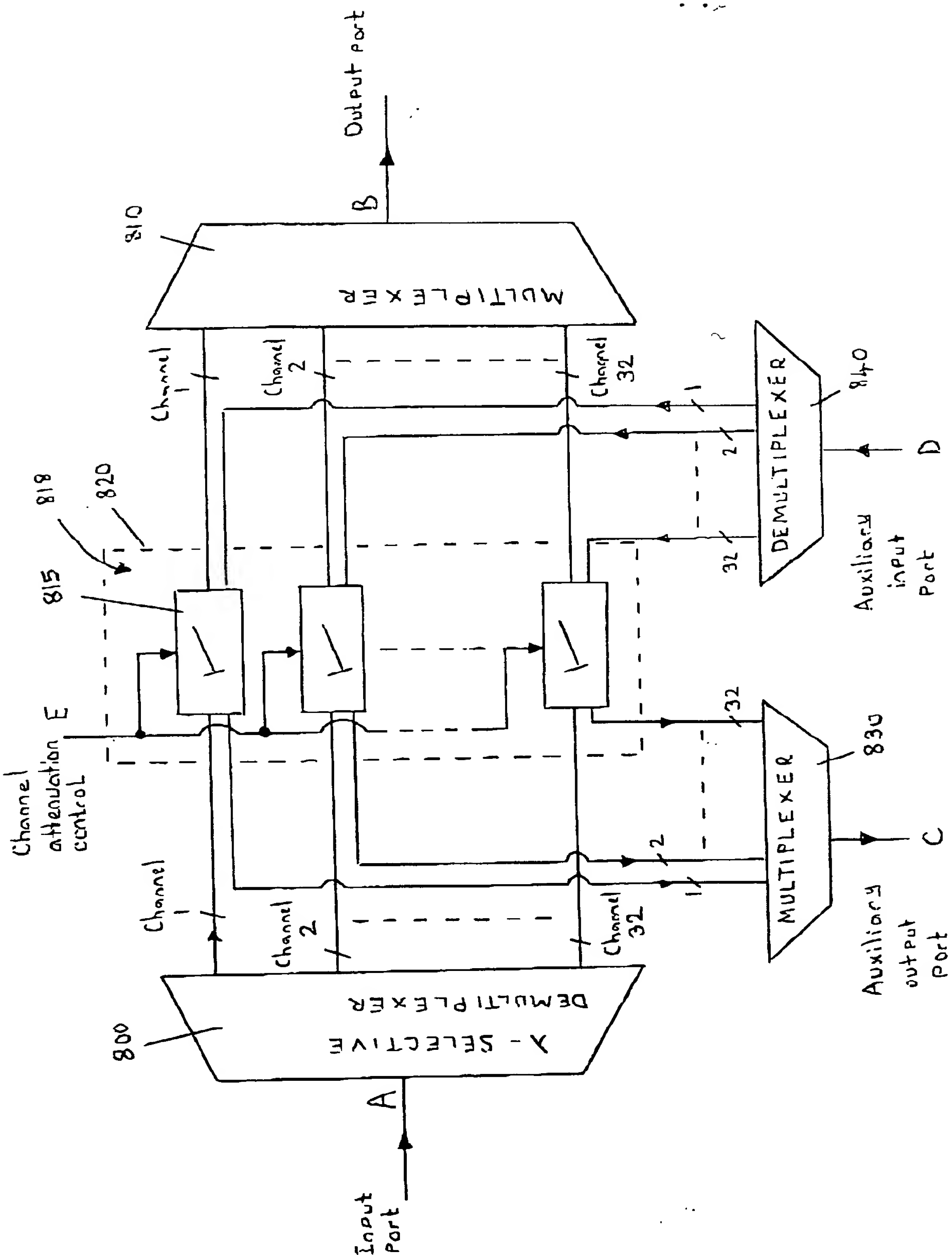
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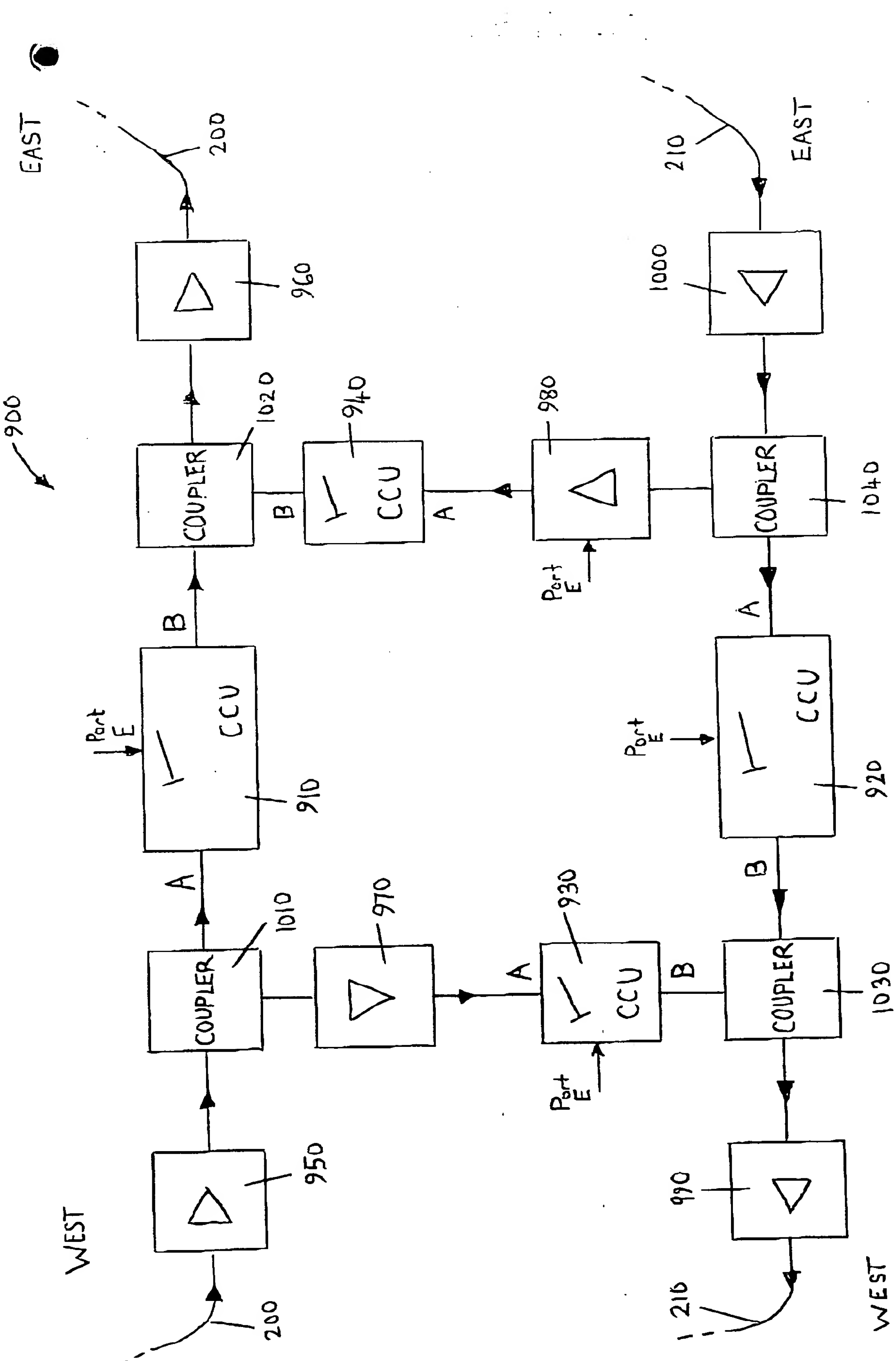
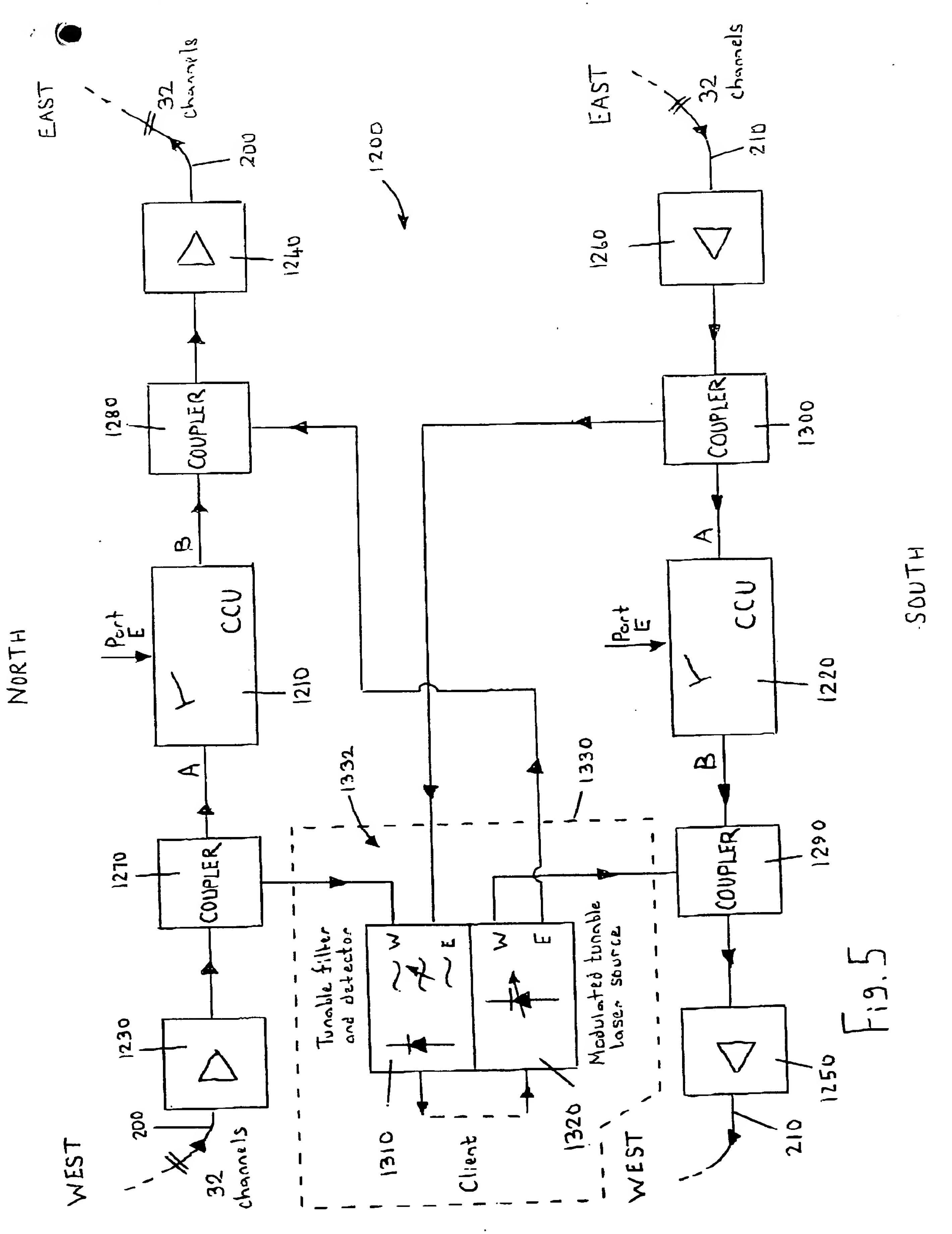
B
810
MULTIPLEXER
Channel 1
Channel 2
Channel 32
840
DEMULTIPLEXER
1
2
32
D
Auxiliary input Port
818
820
815
E
Channel attenuation control
830
MULTIPLEXER
32
2
1
C
Auxiliary output Port
Channel 1
Channel 2
Channel 32
λ - SELECTIVE DEMULTIPLEXER
800
A
Input Port

Fig. 3



EAST
200
960
900
COUPLER
1020
B
CCU
940
A
980
Port E
COUPLER
1040
1000
210
EAST
B
Port E
CCU
910
A
Port E
CCU
920
COUPLER
1010
970
A
CCU
930
B
Port E
COUPLER
1030
B
950
WEST
200
990
210
WEST

Fig. 4



EAST
32 channels
200
1200
1240
1280
COUPLER
B
Port E
CCU
NORTH
1210
A
1270
COUPLER
1230
WEST
32 channels
200
1332
1330
Tunable filter and detector
W
E
W
E
Modulated tunable laser source
1310
1320
Client
WEST
210
1250
1290
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CCU
A
SOUTH
COUPLER
1300
1260
EAST
32 channels
210

Fig. 5

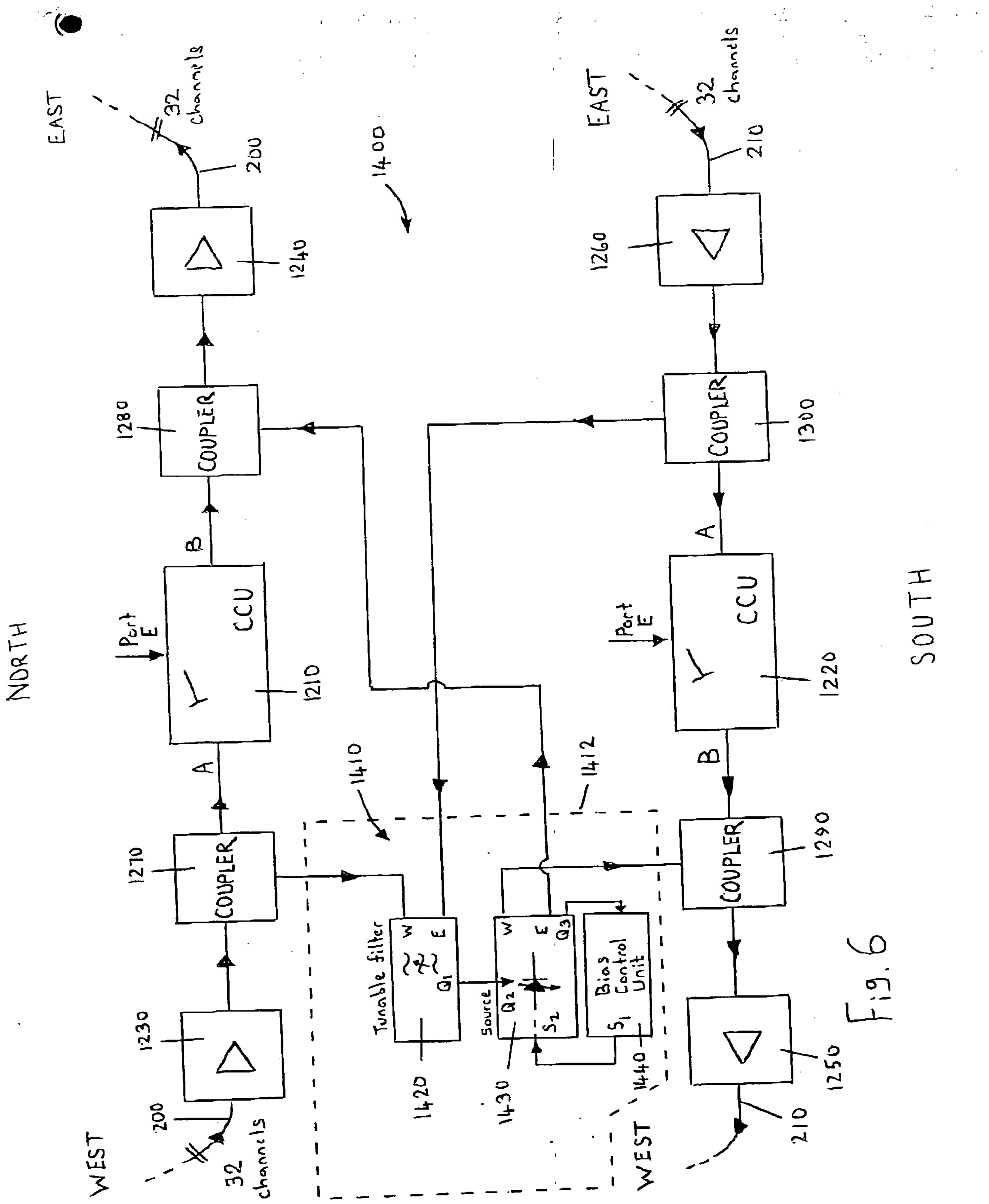

Fig. 6

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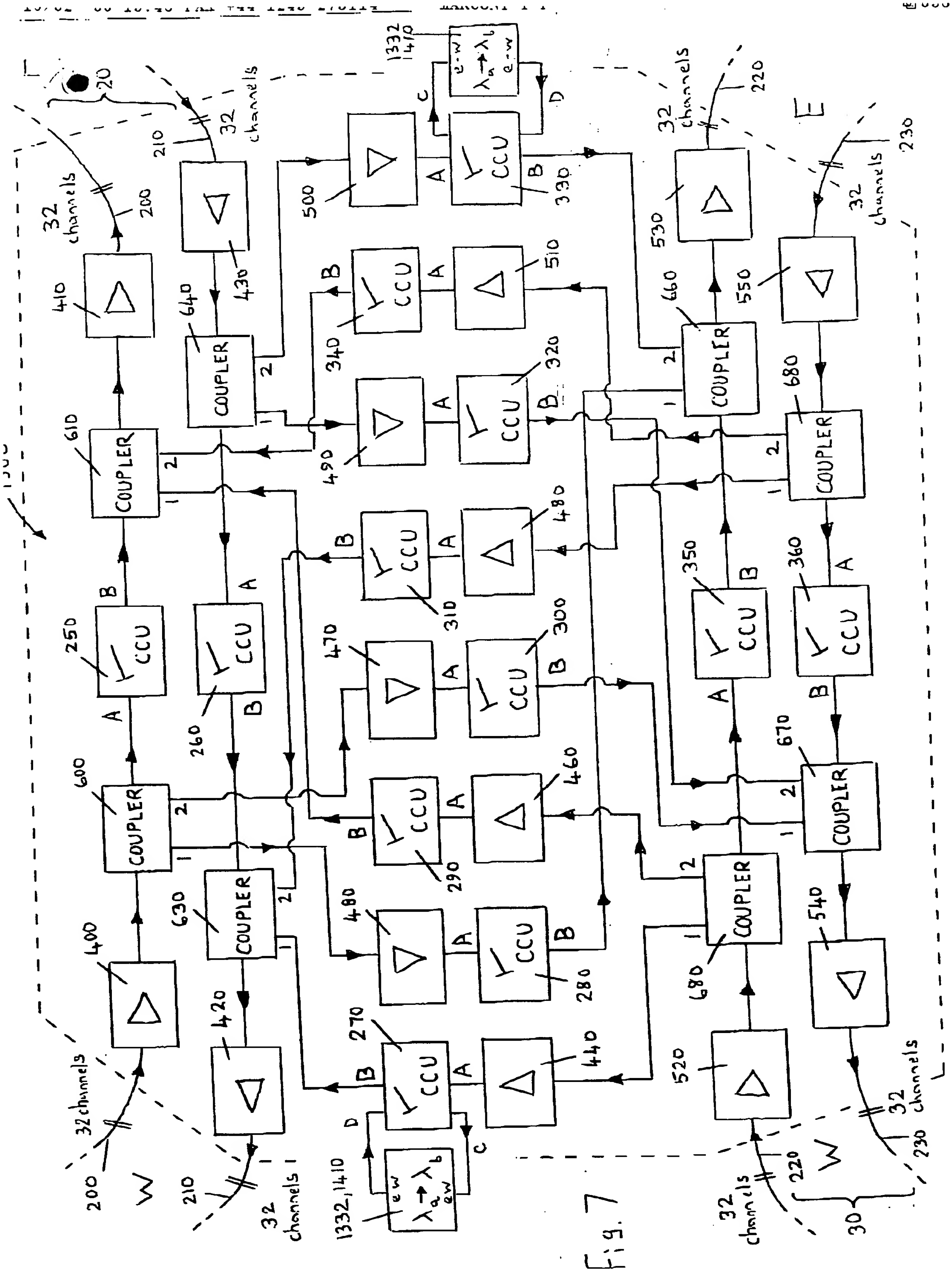

Fig. 7

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